Study of efficiencies and phase centers of broadband log-periodic feeds for large offset dual-reflector antennas using formulas for bodies of revolution (BOR_1 extraction)

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1 Introduction

The Allen Telescope Array (ATA) is a new instrument being built by the SETI institute. It is an array of offset Gregorian reflector antennas and will have a very large bandwidth, covering 0.5 GHz to 11 GHz. We have analyzed a log-periodic feed that covers the frequency range with low losses and low noise. The feed was designed by Greg Engargiola at University of Berkely, California [1]. It consists of four log-periodic arms, together forming a pyramid. In the center of the pyramid, a metallic pyramid is located, holding low noise amplifiers and cryogenics [1]. Figure 1 shows the geometry of the feed. The feed is also being considered for the proposed Square Kilometer Array (SKA).

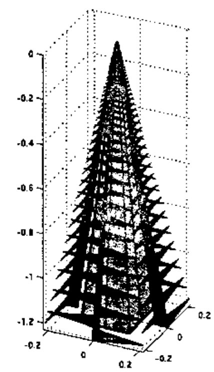

Figure 1: Geometry of the ATA feed.

We have done extensive numerical analysis of radiation patterns of the feed and we have used these to calculate its performance in the reflector system in a simple and effective way. The reflector performance includes the aperture efficiency and its sub efficiencies calculated using simple formulas for bodies of revolution (BOR). The actual reflector system is not a BOR, but still the BOR efficiencies will characterize the feed performance. This method requires that the BOR_1 component is extracted from the radiation pattern. The power in other BOR components represent power loss and is accounted for in a BOR_1 efficiency. This paper discusses this method and some results from the analysis of the ATA feed are presented.

2 Definition of efficiencies and phase center

The aperture efficiency e_{ap} is factorized into a number of sub efficiencies according to

$$e_{ap} = e_{BOR_1} e_{sp} e_{ill} e_{pol} e_{\varphi} e_{foc} \tag{1}$$

where e_{sp}, e_{ill}, e_{pol} and e_{φ} are spillover-, illumination-, polarization sidelobe- and phase efficiency respectively [2, chapter 8.4], e_{BOR_1} is the power in undesired φ-modes as defined below and e_{foc} is the focus efficiency as defined below. This method assumes that there is ideally no cross polarization on axis and that the reflectors are rotationally symmetric and

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of classical shape. In an offset Gregorian reflector system, the symmetry is lost, but only the illumination efficiency will differ. If the reflectors are of classical shape, this difference is very small.

There exist simple formulas to calculate the efficiencies given the E- and the H-plane patterns or the 45°co- and cross-polar patterns [3]. These formulas assume that the pattern is of BOR_1 type. Power in other BOR components represents power loss and reduce the aperture efficiency.

In order to use the simple formulas for the efficiencies, the BOR_1-component must be extracted. Every far field function can be Fourier series expanded in φ-direction i.e.

$$\mathbf{G}(\theta,\varphi)=\hat{\theta}\sum_{n=0}^{\infty}A_n(\theta)\sin(n\varphi)+B_n(\theta)\cos(n\varphi)+\hat{\varphi}\sum_{n=0}^{\infty}C_n(\theta)\sin(n\varphi)+D_n(\theta)\cos(n\varphi) \tag{2}$$

The BOR_k component is the $n=k$ part of equation 2. For a y-polarized BOR_1 antenna, the far field function is then

$$\mathbf{G}^{\mathrm{y}}_{\mathrm{BOR}_1}(\theta,\varphi)=G_{\mathrm{E}}(\theta)\sin\varphi\hat{\theta}+G_{\mathrm{H}}(\theta)\cos\varphi\hat{\theta} \tag{3}$$

where G_{E} and G_{H} are the E- and H-plane radiation patterns respectively. The reduction in efficiency caused by power in other BOR components is included in the BOR_1-efficiency in (1). (In [3], this efficiency was denoted as an *azimuth mode efficiency*.) It is defined as the power in the BOR_1 component over the total power.

We use the same definition of the phase center as in [2] and [4], namely:
The phase center is the particular phase reference point that maximizes the phase efficiency, e_{φ}. Normally, the phase center is placed in the focal point of the reflector in order to maximize the aperture efficiency. However, the phase center of the feed analyzed in this paper moves with frequency. The numerical analysis show that the phase center is located approximately 1.3λ from the convergence point of the four log-periodic arms of the feed. For small displacements of the phase center from the focal point, we have [4]

$$e_{\varphi}=e_{\varphi,\max}-a\,(k\delta)^2 \tag{4}$$

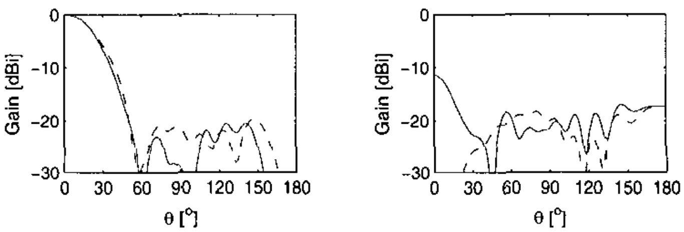
where a is a constant, k is the wave number and δ is the displacement. From this relation the focus efficiency, e_{foc}, can be defined as the phase efficiency over the maximum phase efficiency. Using this relation, it is possible to show that the reduction in phase efficiency for the ATA feed is less than -1 dB over the entire frequency range.

3 Numerical analysis

Simulations are done using the WIPL-D software which is based on the Method of Moments [5]. The phase efficiency is calculated assuming that the feed is focused for all frequencies. All simulations are run on a standard desktop computer with 512 MB of RAM.

Note that no symmetry can be used to simplify the calculations. The physical feed structure is rotationally symmetric in steps of 90°, but the excitation does not have the same symmetry, and it is therefore impossible to introduce symmetry planes. For a given frequency, there exists an *active region* where the pennants are resonant. The currents on those pennants that are longer than the resonant length are very small. This makes it possible to simply remove these parts of the feed in the model in order to reduce computation time. By doing this, simulations show minor change to the backward radiation pattern and no change to the forward radiation pattern.

The subtended angle θ_H defined by the edge of the secondary reflector is 42°[1].



(a) 45° copolar gain pattern.

(b) 45° crosspolar gain pattern.

Figure 2: Radiation patterns at 9.5 GHz in the 45°-plane. Solid line is the total pattern and the dashed line is the BOR_1-component.

The log-periodicity states that the performance is identical at frequencies $f = \tau^n f_b$ where τ is the log-periodicity, f_b is a base frequency and n is an integer [6]. Thus we only need to simulate in the frequency rang $\tau f_b < f < f_b$. However, this does not account for truncation of the structure. Therefore, we also need to simulate at the lowest and highest frequencies. In this paper, only results from simulations at the higher frequencies are presented.

Figure 2 shows the radiation pattern at 9.5 GHz. This frequency was chosen since it turned out to represent the entire frequency band quite well. The -12 dB beamwidth is roughly 42°.

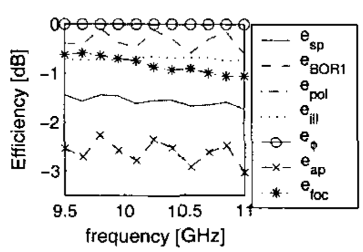


Figure 3: Efficiencies from 9.5 to 11 GHz. Note that the focus efficiency, e_{foc}, is not included in the aperture efficiency, e_{ap}.

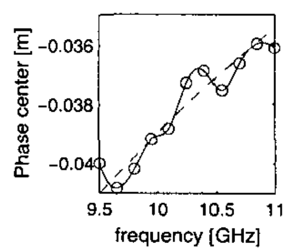


Figure 4: Phase center position.

From the simulated radiation patterns, the efficiencies are calculated. Results from these calculations are shown in figure 3. We can see that the largest negative contributor to the aperture efficiency is spillover. The illumination efficiency is steady around -0.7 dB. The BOR_1 efficiency is better than -0.5 dB.

Phase center movement over the frequency range is shown in figure 4. The solid line is the calculated phase center and the dashed line is -1.3λ for comparison. The phase center is calculated at the marked points and cubic spline interpolation is used to get the smooth curve.

4 Conclusion

We have presented a method for analyzing dual reflector systems based on BOR_1-extraction. This method does not consider shape of the reflectors or edge diffraction at the secondary reflector.

The performance of the ATA feed in the offset Gregorian dual reflector has been analyzed with this method. With a good corrugated feed in a paraboloid or Casegrain antenna, the spillover efficiency would typically be around -0.5 dB for the subtended angle giving the highest efficiency [2, chapter 8.4]. The spillover efficiency for the ATA feed is around -1.5 dB, which is caused by high sidelobes.

In order to increase performance of the system, the sidelobes should be reduced. We have found that 0.5 dB gain can be accomplished by changing the shape of the ground pyramid in the center of the feed to a cone. This will reduce the spillover and increase the BOR_1 efficiency.

With optimized placement of the feed in the reflector, the reduction of phase efficiency due to phase center movement is better than -1 dB. Considering the bandwith of the feed, this is very good.

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